

ANTENNA TECHNOLOGY FOR
QUASAT APPLICATION

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INTRODUCTION

This paper summarizes the results of a TRW study performed to provide JPL with antenna cost and design data for use in assessing the technical feasibility of QUASAT, a very long baseline interferometry (VLBI) mission in space. Science requirements for this mission have been defined by the NASA OVLBI Technical Working Group and the European Space Agency QUASAT Working Group (Paris, Oct. 1983). The mission concept involves a free-flying high-earth-orbiting spacecraft which carries a space-deployable radio antenna of about 15 meters in diameter with a receiving capability at K, C, and L bands.

TRW's approach to the requirements of the QUASAT antenna configuration adapted a hybrid growth version of the advanced Sunflower, or precision deployable, antenna concept. The basic precision deployable antenna concept uses a furlable rigid-panel reflector design as illustrated in figure 1, where it is shown mounted in the Shuttle bay.

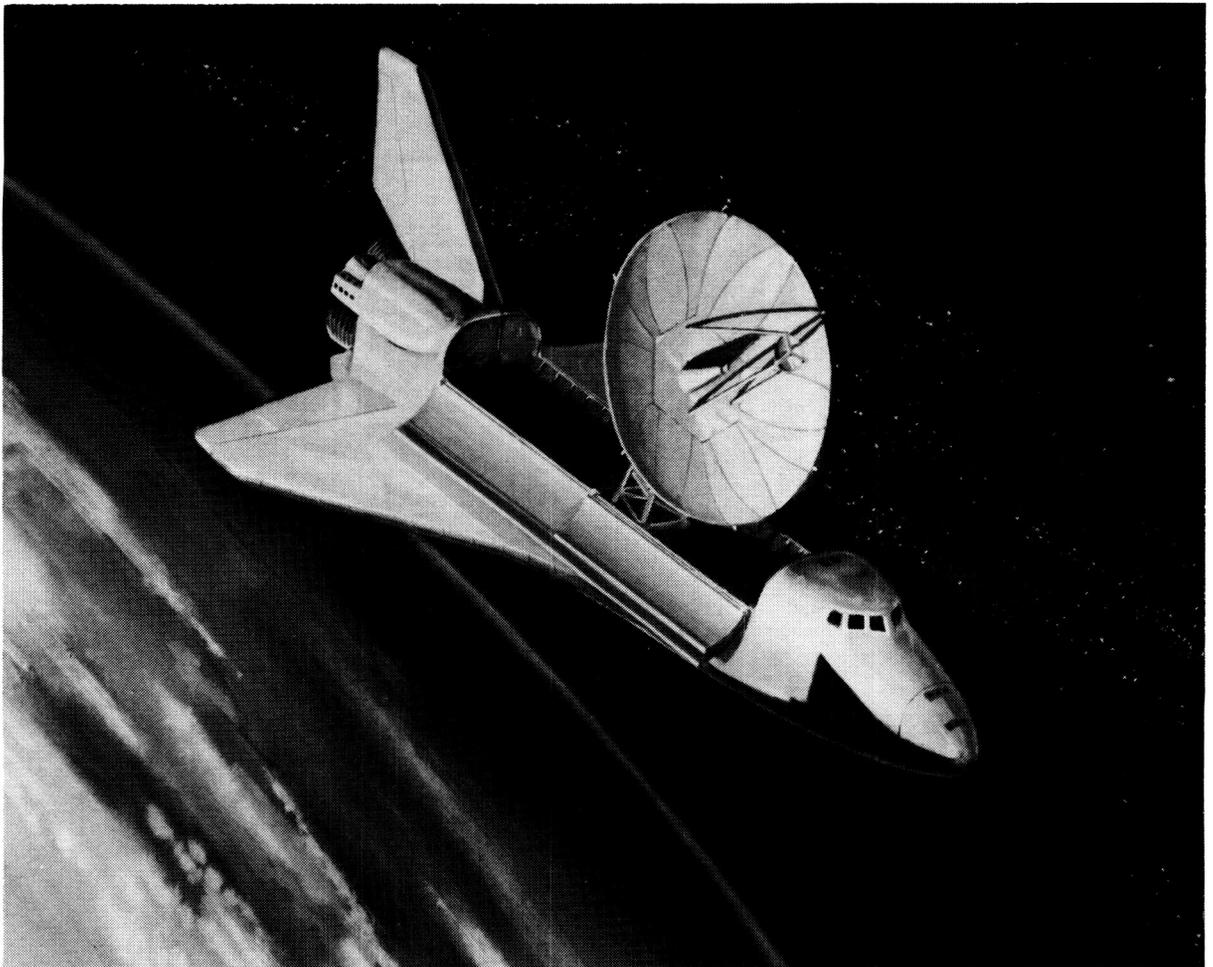


Figure 1. Precision deployable antenna in the Shuttle's bay.

PRECISION DEPLOYABLE CONCEPT

TRW has been actively investigating the design of precision deployable antennas for several years. Figure 2 is an illustration of a 12-inch-diameter working model. Developed for a precision-contour reflector application, the concept can accommodate Cassegrain or focal-fed antenna applications requiring high-efficiency high-frequency apertures.

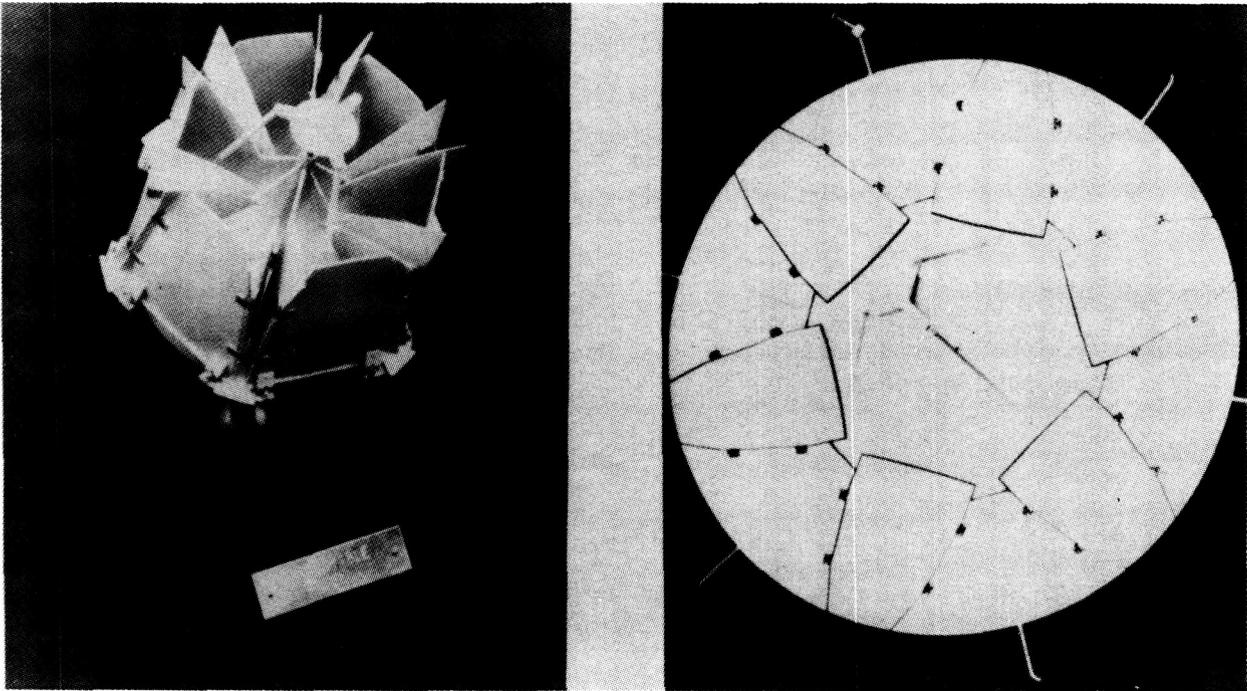


Figure 2. Deployable symmetrical aperture.

27.5-FOOT RESEARCH MODEL

Figures 3 and 4 show a design and the tooling which have been developed in TRW's ongoing research and development program for the precision deployable antenna. Information from this ongoing effort was used to prepare the technology and costing data provided in the figures which follow.

To provide a stiff, near-continuous surface, the antenna sections consist of rigid panels of graphite-epoxy facesheets covering aluminum honeycomb core sandwich. The center section, the one-piece honeycomb sandwich structure, is centered within the folding sandwich sections.

The six main folding panels are hinged to a cantilevered support ring attached to the periphery of the center section. Between the six main panels on the cantilevered ring are six pairs of intermediate panels. Two or more hinges along adjacent edges connect each pair of intermediate panels to the main panels and to each other. The hinges have adjustable stops which locate the panel surfaces accurately in the deployed configuration. Springs in the hinges drive the panels to the deployed position. To ensure synchronization of all panels during deployment, a compound universal coupling interconnects adjacent inboard hinges of the main panels. Either a damping device or a geared motor controls the deployment rate. On ordnance-actuated pin puller supported on one of the tie-down fittings restrains the furled antenna. The number of panels hinged from the fixed center section can be varied as required to optimize the diameter and height of the stowed antenna.

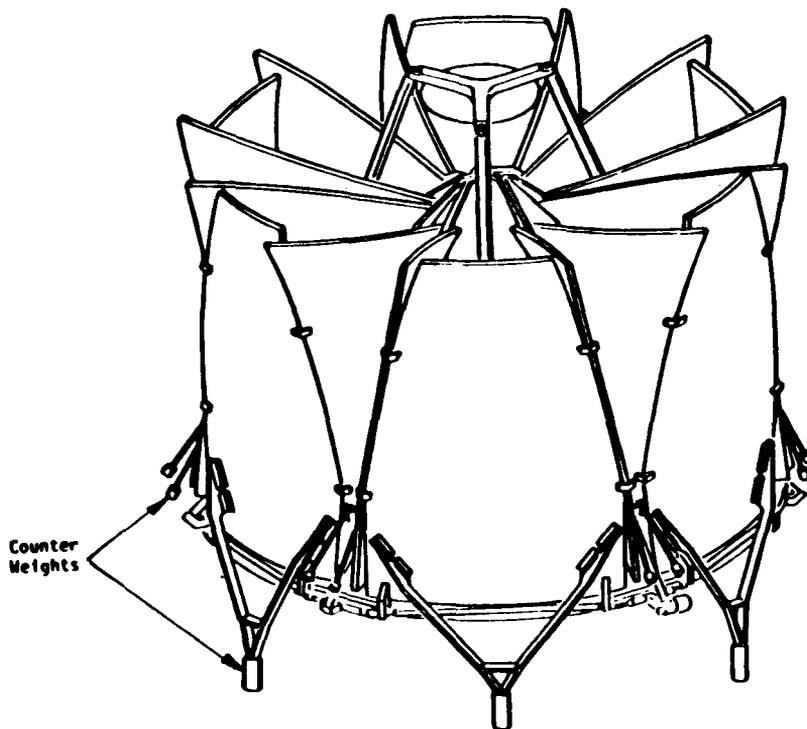


Figure 3. 27.5-foot-diameter deployable solid reflector (stowed).

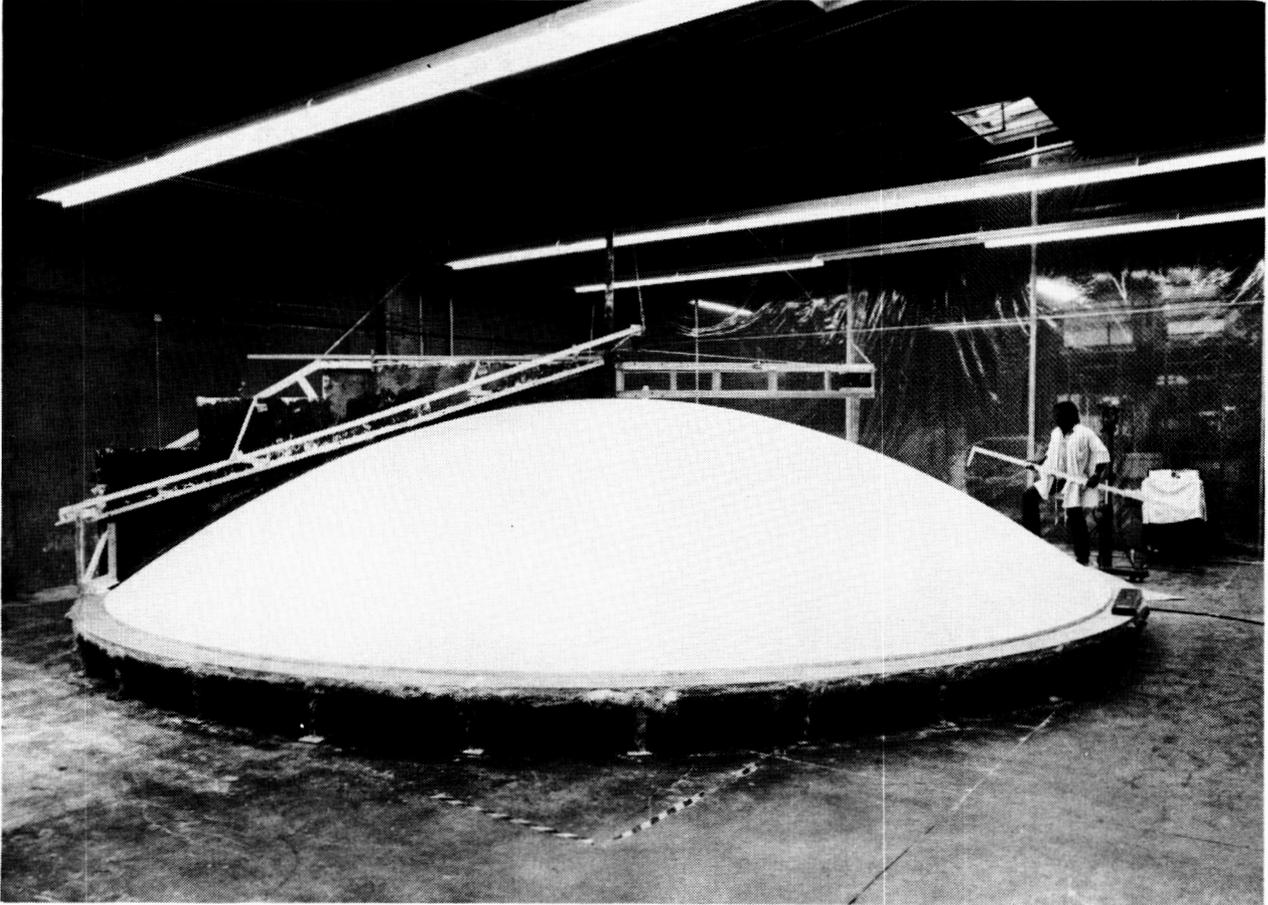


Figure 4. Master layup mold.

QUASAT REQUIREMENTS

The following specific mechanical requirements constrained the TRW QUASAT study:

- (1) The antenna shall be a deployable reflector configuration.
- (2) The antenna shall be stowable within the Shuttle Orbiter bay.
- (3) The antenna characteristics shall be assessed for a range of apertures from 10 (33) to 20 (66) meters (feet).
- (4) The antenna surface error shall not exceed 0.8 millimeter (0.031 inch).
- (5) The mechanical parameters to be assessed shall include antenna weight, mass properties, stowed envelope, structural interface details, manufactured surface contour, thermal distortion, and materials of construction.
- (6) Cost and schedule parametric data shall be provided.

QUASAT HYBRID ANTENNA CONFIGURATION

Technical parametric data are provided for antenna diameters of 10 (33), 15 (49), and 20 (66) meters (feet). For each antenna diameter (D), we selected a focal length (F) to maintain a constant F/D ratio of 0.4. In selecting the antenna configurations for each diameter, we designed the stowed envelope dimensions to fit within the Shuttle launch vehicle envelope. This constraint limits the maximum allowable precision Sunflower aperture to 33 feet. A 33-foot-diameter aperture stows in a cylindrical envelope 14.5 feet in diameter by 12.2 feet long. Any larger diameter would exceed the available Shuttle envelope diameter. The hybrid approach, which we discuss below, uses the precision deployable reflector as the core of a larger aperture. The hybrid concept was selected because it offers a practical means of effectively extending the deployable concept with its precision contour advantage to diameters larger than 33 feet while remaining within a stowed envelope of 14.5-foot maximum diameter.

The configurations selected are based upon a common, rigid-panel, precision deployable reflector with an aperture diameter of 33 feet, a size which remains constant for all antenna diameters. Such a central deployable reflector is illustrated in figures 5 to 7. The reflector has the inherent capability of being manufactured with a very low contour root mean square (rms), in the range of 0.005 to 0.015 inch. For the purpose of this study, a value of 0.014 inch was chosen as sufficient to satisfy the system requirements.

As the aperture diameter increases over 33 feet, the diameter of the precision deployable portion holds constant at 33 feet. The increase in total aperture diameter beyond 33 feet is attained by cantilevering an annular disk structure from the 33-foot-diameter precision deployable structure. The nature of the annular disk structure and its attachment to the 33-foot reflector is such that both the annular disk and the supporting central structure deploy simultaneously, as a single structural system.

The behavior of the annular disk structure is that of a flexible membrane. The advantages of this construction over a central rigid-panel structure are lighter weight and flexibility, allowing for storage within the Shuttle envelope, as seen in figure 7. The disadvantage is higher contour rms tolerances compared to the central 33-foot portion.

A 49-foot antenna of hybrid concept consists of a 33-foot-diameter center structure surrounded by an annular disk of 33 feet inside diameter (i.d.) and 49 feet outside diameter (o.d.), the 33-foot center structure being a precision deployable reflector. The 33/49-foot disk with a flexible membrane surface structurally cantilevers from the central precision deployable reflector. Similarly, a 66-foot antenna of this hybrid concept consists of a 33-foot center structure surrounded by an annular disk of 33 feet i.d. and 66 feet o.d. Again, the 33-foot center structure is a precision deployable reflector, and the 33/66-foot disk structure is a flexible membrane surface structurally cantilevered from the central precision deployable reflector.

QUASAT HYBRID ANTENNA CONFIGURATION (CONCLUDED)

Constraint and Release

The stowed configuration for the 33-foot aperture is illustrated in figure 5. Extension arms from the intermediate petals are locked together in the stowed case to provide a rigid integrated structure for reacting the launch loads. For the 49- and 66-foot apertures with the cantilevered annular disk structures, an external ring, when stowed, rigidly constrains the central deployable structure, as illustrated in figure 6. The outer edges of the annular disk are constrained at a point above the feed support structure. The release mechanism is shown in View A-A. In both cases, release is effected by pyrotechnic pin pullers, and deployment is actuated by passive springs and controlled by hydraulic dampers.

Support Interface

The support interface attachment to the spacecraft is illustrated in figures 5 and 6, and the fitting locations are identified in figure 7. This interface is identical for all apertures.

Materials

The antenna is fabricated of graphite-epoxy materials. The central deployable reflector is constructed of sandwich panels made of graphite fiber reinforced plastic (GFRP) facesheets over an aluminum honeycomb core. Deep ribs of the same materials reinforce the panels. These materials provide a rigid, thermally stable structure of relatively light weight. The antenna surface is coated with vacuum-deposited aluminum to provide high RF reflectivity. The final coating is of a 0.003- to 0.004-inch-thick thermal control paint which minimizes specularly and reduces the equilibrium temperature of the reflector structure in the orbital solar environment.

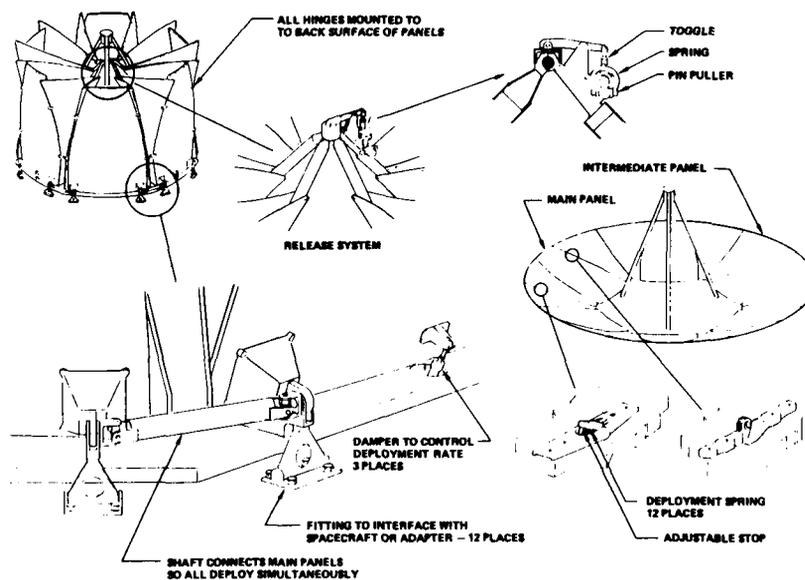


Figure 5. 33-foot-diameter antenna.

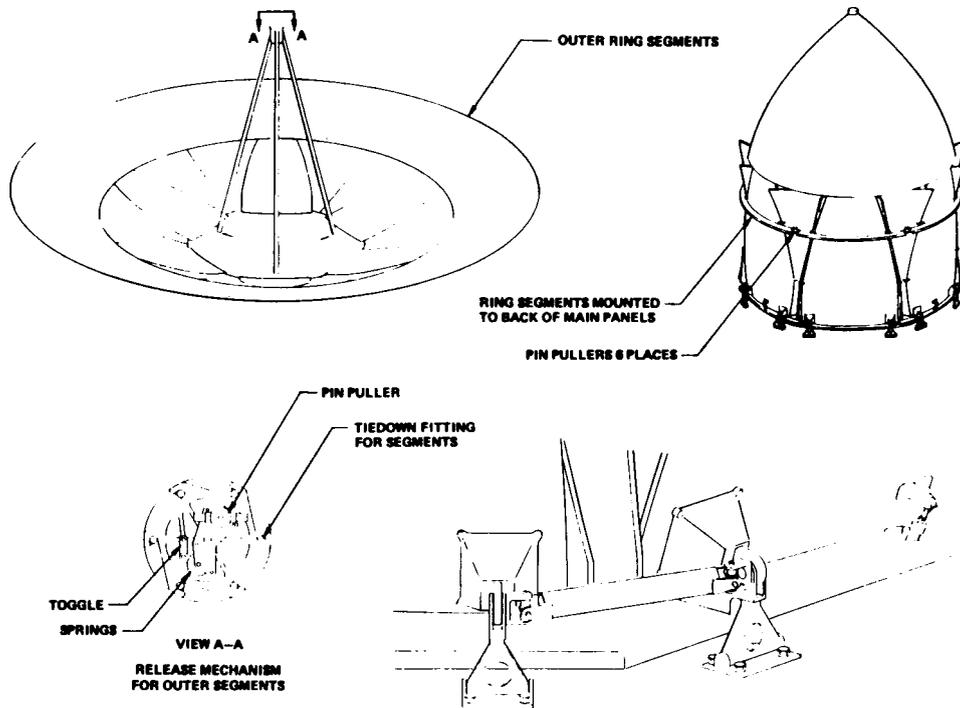


Figure 6. Configuration of 49- and 66-foot-diameter antennas.

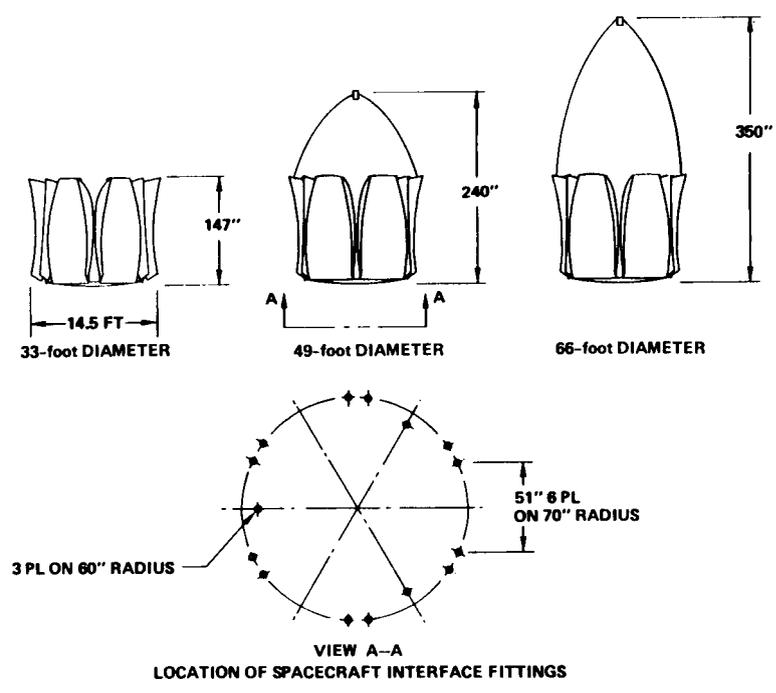


Figure 7. Stowed envelopes (F/D = 0.4).

QUASAT FLIGHT CONFIGURATION

The QUASAT flight configuration using the hybrid antenna configuration is illustrated in figure 8. The furled configuration stowed in the Space Transportation System (STS) bay is illustrated in figure 9.

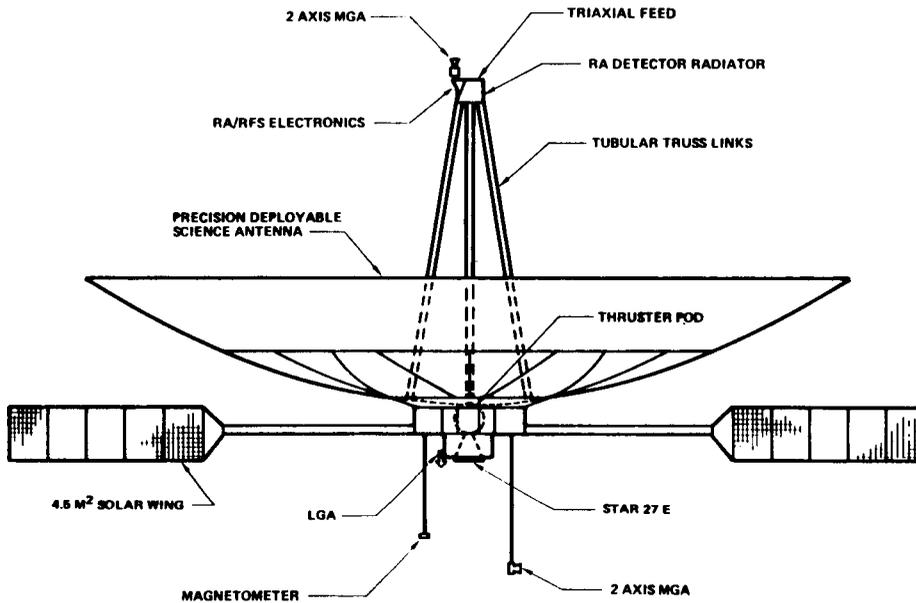


Figure 8. QUASAT flight configuration for advanced sunflower reflector.

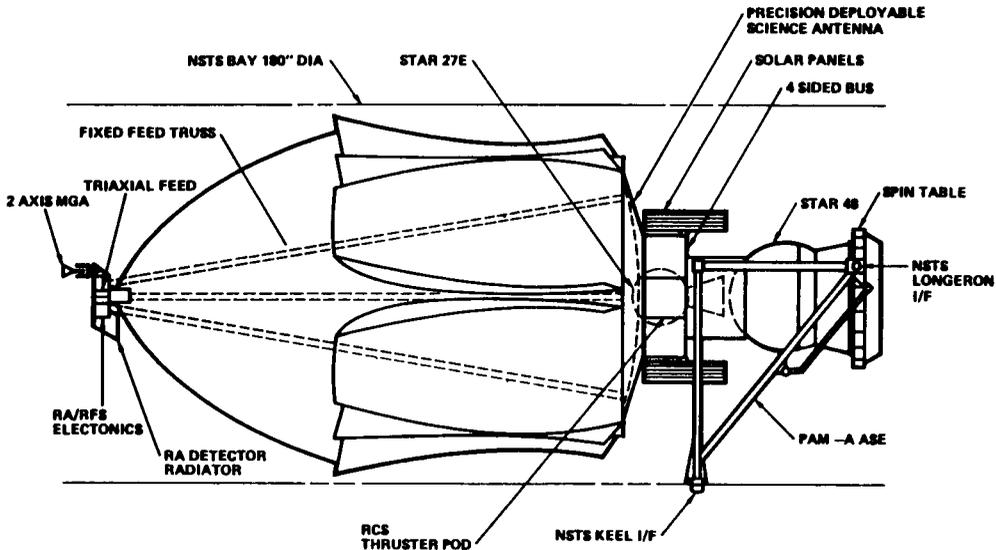


Figure 9. QUASAT advanced sunflower antenna stowed for launch in STS bay.

HYBRID ANTENNA WEIGHT

TRW's experience with solid reflector construction of many types has shown that antenna weights vary from 0.4 to 1.0 psf of the projected aperture. The highest value is from a very conservative design, which is about 15 years old, whereas the lowest value is indicative of current lightweight large reflector experience. To represent the center portion of the antenna, we have used an average value of 0.6 to 0.7 psf including the weight of the feed support tower and launch constraint mechanisms.

The weight of the annular disk structure is estimated at 0.1 psf. The total reflector weight and the breakdown in weight between the center deployable structure and the outer disk are tabulated in figure 10 and plotted in figure 11 for apertures of 33, 49, and 66 feet.

D (feet)	WEIGHT (lb)		
	CENTER DEPLOYABLE STRUCTURE	ANNULAR DISK STRUCTURE	TOTAL
33	500	0	500
49	550	110	660
66	800	255	855

Figure 10. Weight distribution in antenna structure.

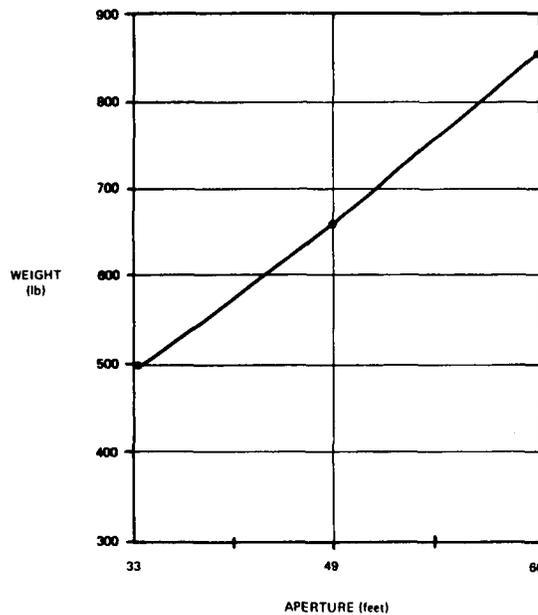


Figure 11. Antenna weight versus aperture.

HYBRID ANTENNA MASS PROPERTIES

The center of gravity (cg) and the moments of inertia have been based on the stowed and deployed geometric envelopes illustrated previously. The antenna focal-length-to-diameter ratio is constant at 0.4 for all apertures from 33 to 66 feet. Furthermore, the antenna mass is largely concentrated in the central portion of the structure. This results in a relatively constant value of the longitudinal position of the cg for the deployed antenna, except for the effect of the feed support tower.

In the stowed configuration, the cg position estimate is based on the stowed envelope geometry and the mass distribution whereas the estimate of the cg position in the deployed case is based on the deployed envelope geometry and the mass distribution. Figure 12 provides the calculated cg data.

The roll moments of inertia when stowed and deployed are provided in figures 13 and 14.

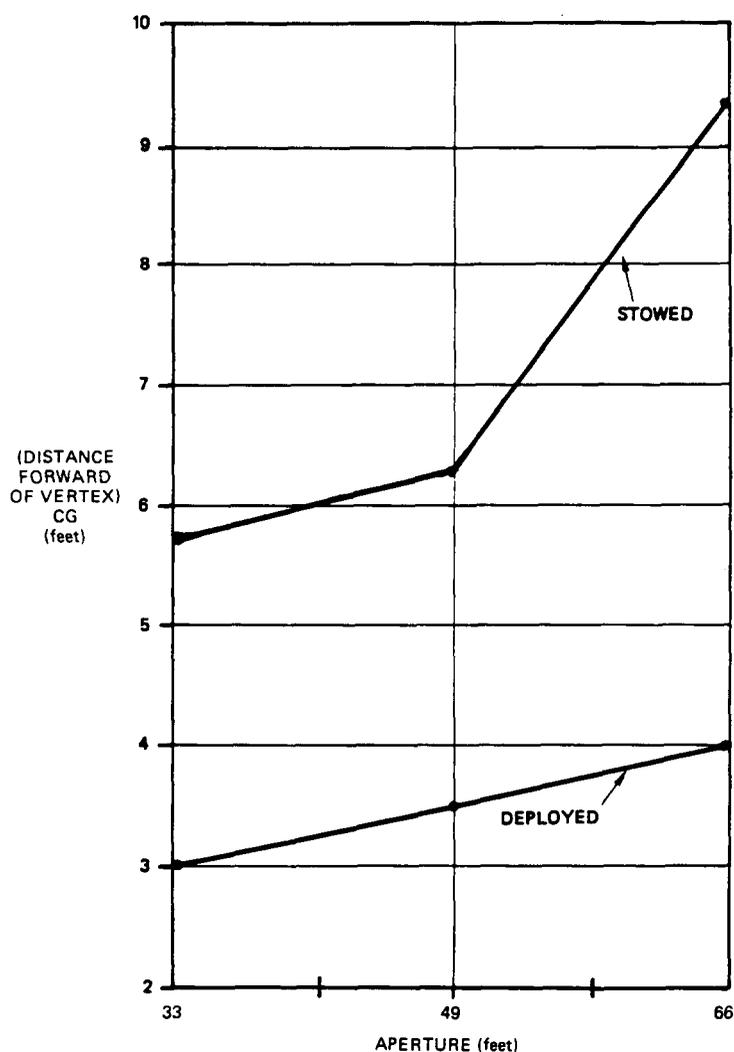


Figure 12. Center of gravity versus aperture.

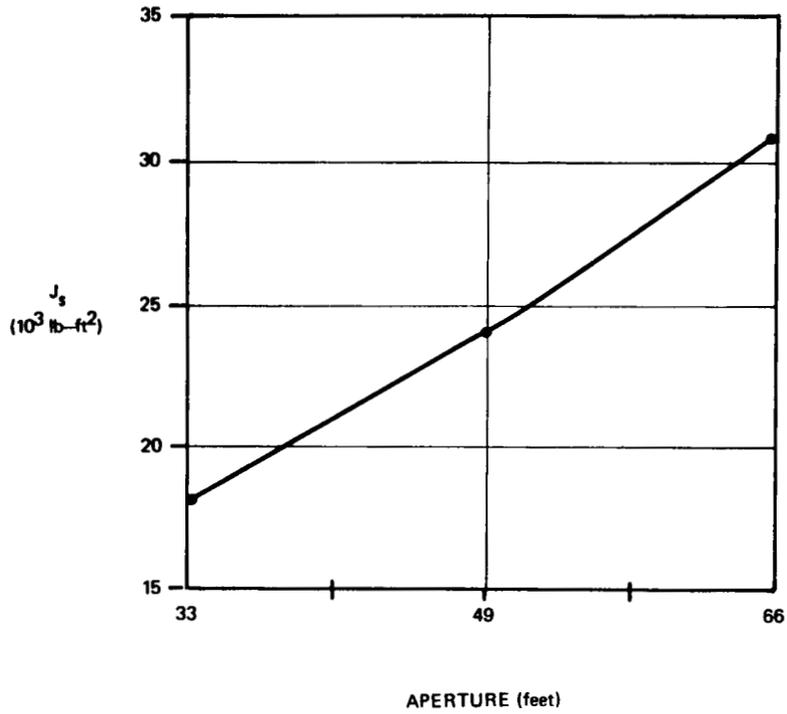


Figure 13. Roll moment of inertia versus aperture (stowed).

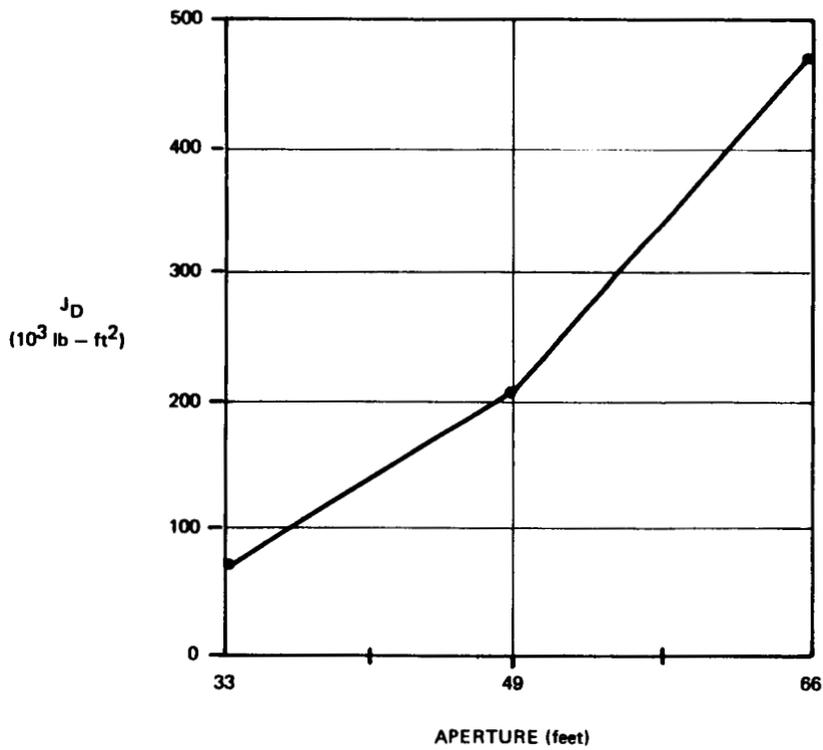


Figure 14. Roll moment of inertia versus aperture (deployed).

HYBRID ANTENNA FREQUENCY

The fundamental frequency of the proposed concept at the various apertures of 33, 49, and 66 feet is based on extrapolation from a known configuration. A detailed vibration analysis was performed on a 20-foot-diameter precision deployable reflector aperture. The fundamental frequency in the stowed configuration was 12 Hz and in the deployed configuration, 5 Hz. These data have been extrapolated to the apertures being studied by using a single-degree-of-freedom model and accounting for mass and size changes. Figure 15 depicts the results of our analysis.

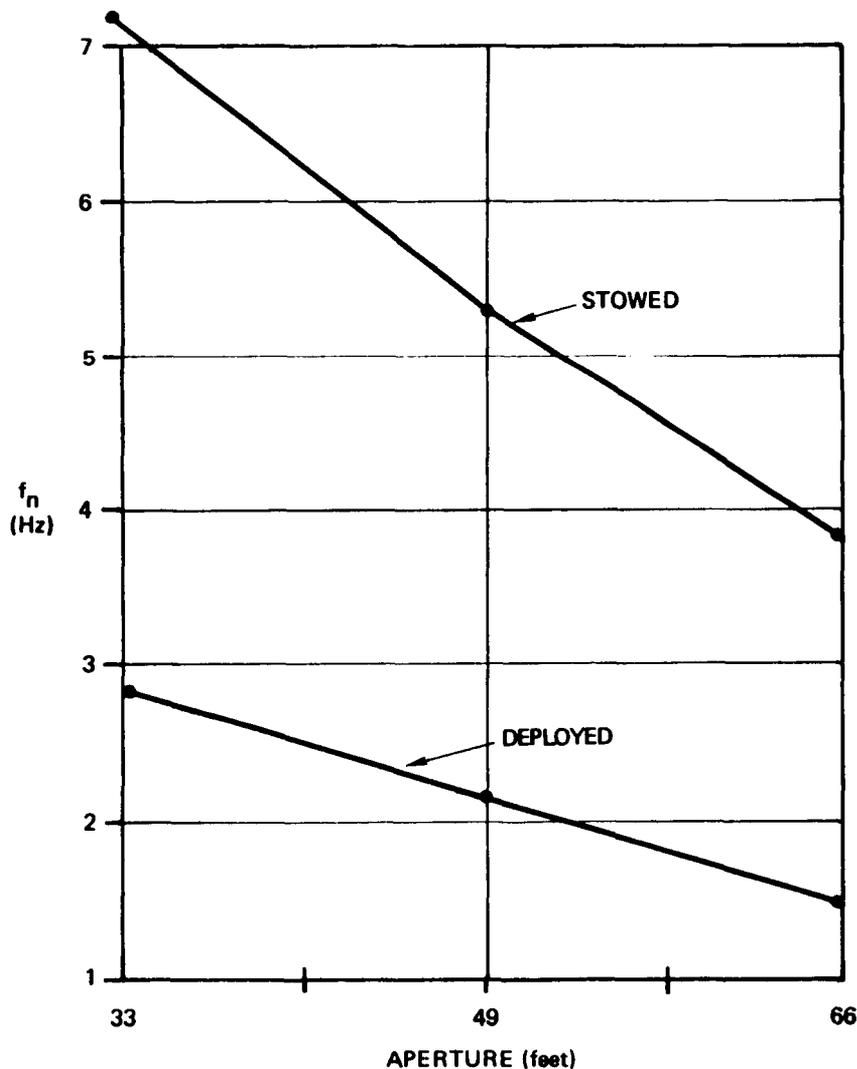


Figure 15. Fundamental frequency versus aperture.

HYBRID ANTENNA CONTOUR TOLERANCE

The hybrid antenna contour distortion is defined as rms deviation from a perfect parabola. The two principal sources of contour error are manufacturing tolerances and thermal distortion on orbit. The total manufacturing error occurs in three areas - fabrication, assembly, and deployment repeatability.

The basic fabrication error is incurred when making the individual panels of the central deployable structure of the antenna. This error, based on experience with different materials and designs, is shown in figure 16. The proposed construction of graphite-epoxy, rib-supported shells will provide a contour rms-to-diameter ratio of 0.00003. The largest panel of the central reflector has a maximum dimension of 12 feet. We may, therefore, expect the panels to individually have an rms of 0.004 inch under ideal conditions. To be conservative, we allowed a 100-percent safety factor and, in addition, assumed that assembly and repeatability errors have the same order of magnitude. The net result is a total rms, including all effects, of 1.732 times 2 times 0.004 = 0.014 inch for the central 33-foot portion of the antenna.

The rms of the annular disk portion of the antenna is related to the method of support of the flexible membrane. The support structure is selected to maintain a fabricated rms of 0.033 inch for the 66-foot disk. The assembly and deployment repeatability errors are assumed to equal those for the central deployable structure.

The net results for the center and annular segments and for the complete 33-, 49-, and 66-foot antennas are tabulated in figure 17. The total combined rms is determined by root-sum-squares using area weighting for the components.

We estimated the thermal distortion by extrapolation from existing analyses on smaller apertures. A conservative value for graphite-epoxy construction is 0.001-inch rms for a 5-foot-diameter aperture. Linear extrapolation gives rms values of 0.007 inch for 33 feet, 0.010 inch for 49 feet, and 0.013 inch for 66 feet. These values, found in figure 17, when combined with the net manufactured rms give the total on-orbit rms values for each case.

The total on-orbit rms performance satisfies the system requirements for all aperture sizes.

MATERIAL	CONFIGURATION	NORMALIZED CONTOUR RMS (δ/D)
FIBERGLASS	SANDWICH SHELL	$> 5 \times 10^{-4}$
	ADJUSTED SHELL	0.7×10^{-4}
KEVLAR	RIB-SUPPORTED SHELL	0.6×10^{-4}
ALUMINUM	SANDWICH SHELL	0.5×10^{-4}
GRAPHITE	SANDWICH SHELL	0.9×10^{-4}
	RIB-SUPPORTED SHELL	0.3×10^{-4}
	ADJUSTED SHELL	0.14×10^{-4}

Figure 16. Nondeployable reflector performance correlation.

(INCHES)

APERTURE	33 ft	33-49 ft	49 ft	49-66 ft	66 ft
WT'D AREA	(1)	(1.25)	(2.25)	(1.75)	(4)
ERROR SOURCE					
FABRICATION	0.008	0.025		0.033	
ASSEMBLY	0.008	0.008		0.008	
DEPLOYMENT	0.008	0.008		0.008	
NET MANUFACTURED RMS	0.014	0.028	0.023	0.035	0.029
THERMAL DISTRIBUTION	0.007		0.010		0.013
TOTAL ON-ORBIT RMS	0.016		0.025		0.032

Figure 17. Contour RMS versus aperture.

MODIFIED 49-FOOT STOWED CONFIGURATION

STS launch costs are strongly dependent upon the length of bay occupied by the payload to be carried into orbit. The principal problem with the hybrid configuration is the length of the stowed antenna envelope.

The stowed envelope can be shortened by almost 8 feet for the 49-foot antenna by folding the outer-rib mesh annular disk onto the surface of the solid segmented panels of the inner 33-foot-diameter precision deployable antenna. This is accomplished by changing the hinge mechanism on the outer ribs and revising the stowage sequence. The solid panels of the precision deployable antenna are subsequently stowed while supporting the folded ribs of the outer annular portion. This stowage technique is illustrated in figures 18 to 20. It cannot be used for the 66-foot antenna because the ribs in the annular disk are too long to be folded onto the folding panels of the 33-foot central antenna structure.

In order to take full advantage of the reduced length of the STS bay required for launch, the feed support structure must also be made stowable, as shown in figure 21, which illustrates the revised stowage envelope in the STS bay.

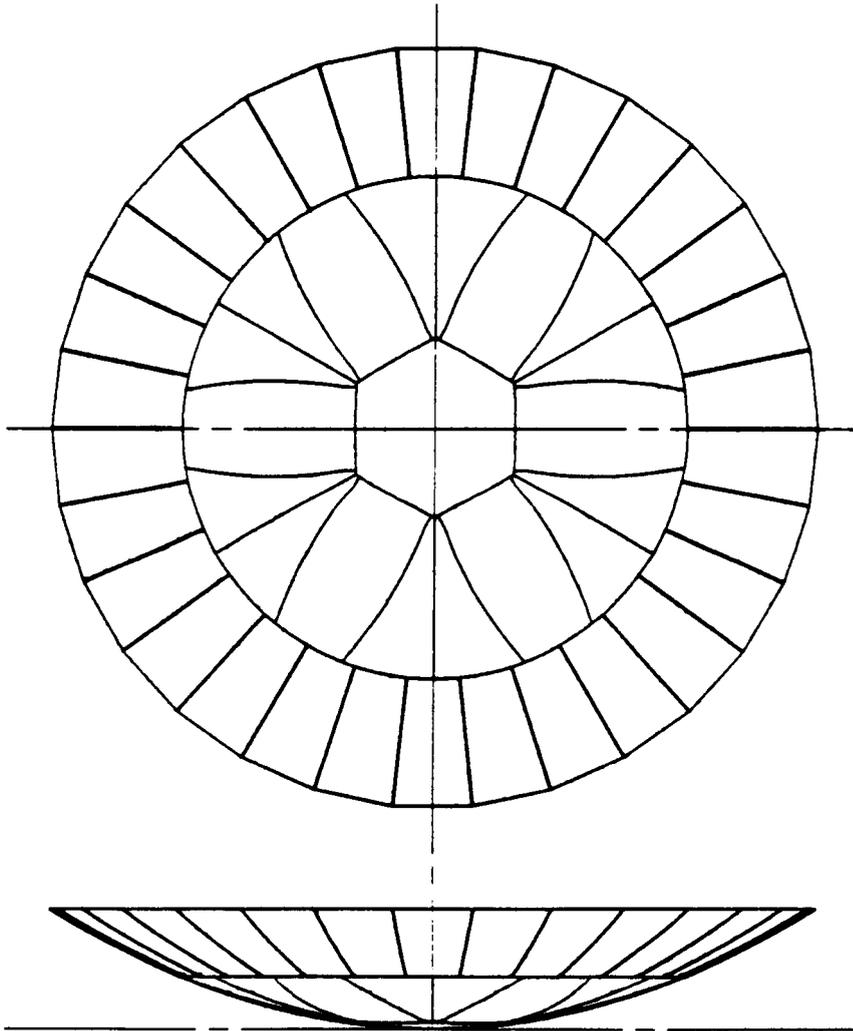


Figure 18. Deployed 49-foot hybrid antenna with modified stowage technique.

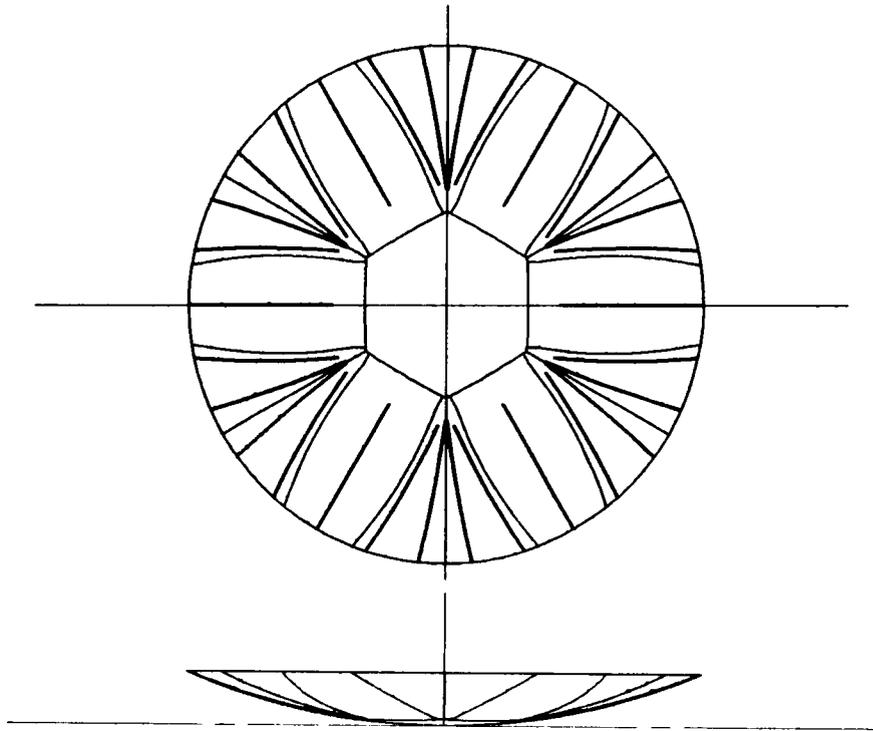


Figure 19. Partially furled 49-foot hybrid antenna with modified stowage technique.

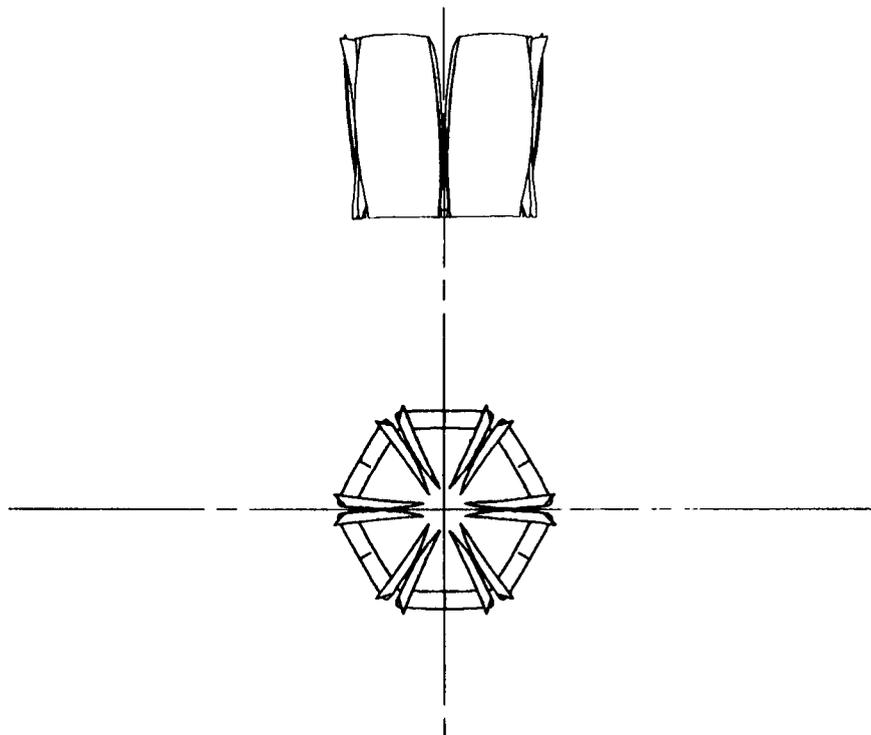


Figure 20. Completely furled 49-foot hybrid antenna with modified stowage technique.

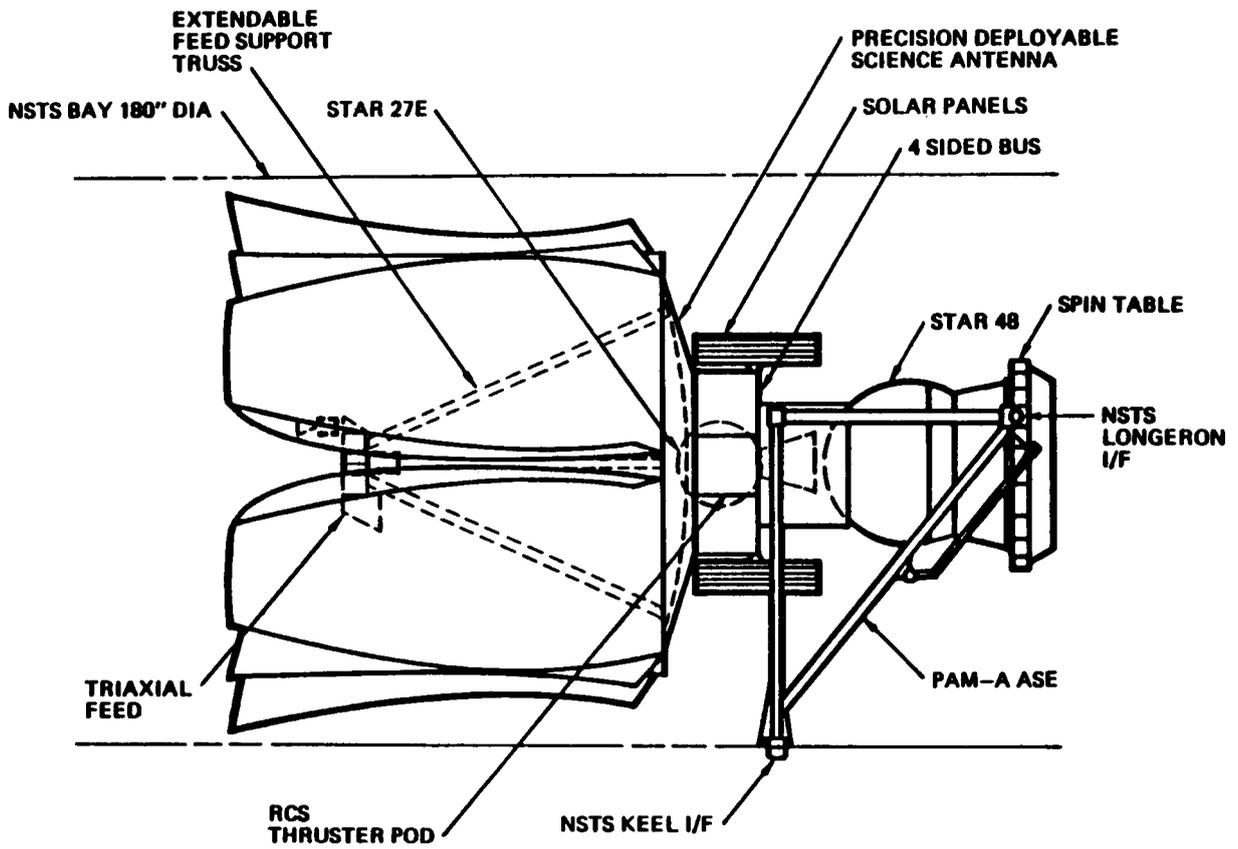


Figure 21. QUASAT 49-foot hybrid antenna stowed in STS bay for launch with modified stowage envelope.

CONCLUSION

For the QUASAT antenna, the hybrid concept discussed here is a promising alternative to an all-mesh contour. The greater efficiency of the solid antenna surface, the tighter tolerances possible with the solid folding panels, and the potential for using the center 33-foot portion for higher RF frequencies than possible with mesh surfaces open up interesting prospects for future accomplishments. The possibility of storing a 49-foot antenna within a short envelope in the Shuttle's bay contributes immensely to the feasibility of the concept.